LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T040139-00-K *Advanced LIGO UK* June 2004

Interferometric OSEM Sensor Development Update

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of the Advanced LIGO Project, prepared by members of the UK team.

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1 Abstract

We report briefly on progress made in the design and further evaluation of the interferometric sensor proposed previously for application in an Advanced LIGO OSEM. We have maintained the overall optical design previously described [1] but have made minor modifications to simplify manufacture. Most significantly we have made a more detailed examination of the noise levels in the optical bench developmental prototype using laser diodes and a He-Ne laser. These new results show that previous measurements were dominated by environmental noise when operating at unequal optical paths in each arm of the interferometer and that, in the current configuration, the laser diodes have a uniform noise of better than $3.5\times10^{-12}\ mHz^{-1/2}$ at $75Hz$ over a range of $1.75mm$ which is comparable with the measured performance of a He-Ne laser. We believe that the noise level at $10Hz$ is dominated by mechanical instability in the optical bench prototype. We have achieved noise performances of $3.1\times10^{-12}\ mHz^{-1/2}$ and $1.7\times10^{-12}\ mHz^{-1/2}$ at $10Hz$ with the laser diode and He-Ne, respectively. We have detailed a full design for an interferometer that satisfies the size constraints specified by the Advanced LIGO project. The limitation to the useful range of operation of the interferometer due to tilt of the target mirror is also now understood.

2 Modified Interferometer Layout

Shown in figure 1 is a schematic of the new configuration. We now have a coaxial geometry with two interferometric outputs rather than three in the previous version. The mean laser power is measured by photodiode *PD1* and this is used to centre the Lissajous pattern. We attenuate the laser to avoid optical feedback using a polariser, *P,* at the input. The overall principle of the device is otherwise unchanged. We believe that this new configuration will simplify the manufacture and miniaturisation of the sensor.

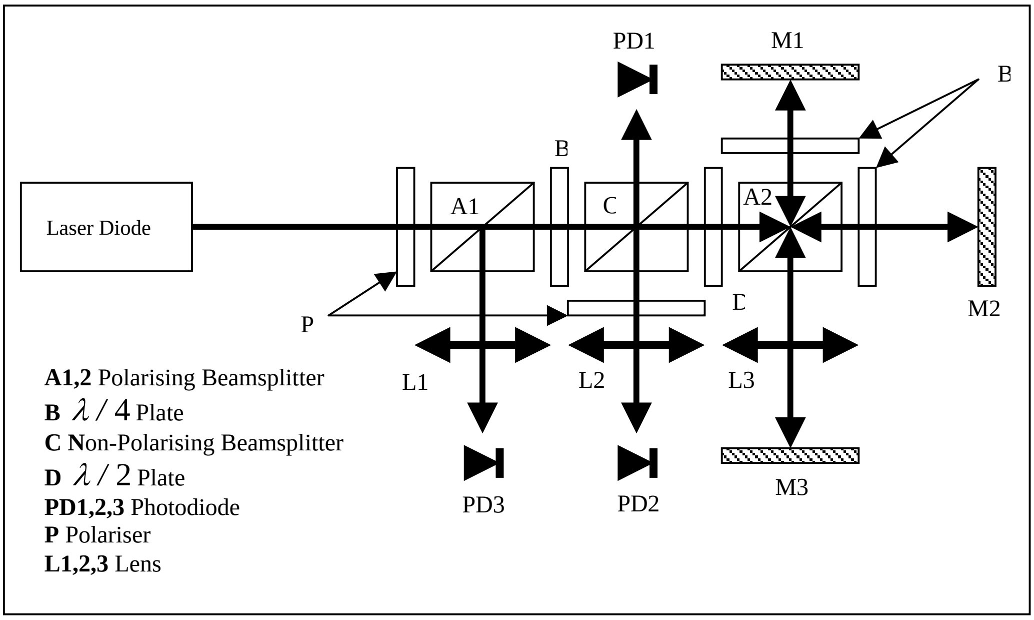

Figure 1. Modified Interferometer Layout

We have incorporated this modified interferometer scheme into the design of a further prototype device. Figure 2 shows a drawing of the next phase prototype interferometric sensor undertaken at Birmingham, which is now approaching the envelope of the final required OSEM sensor (40×70*mm*).

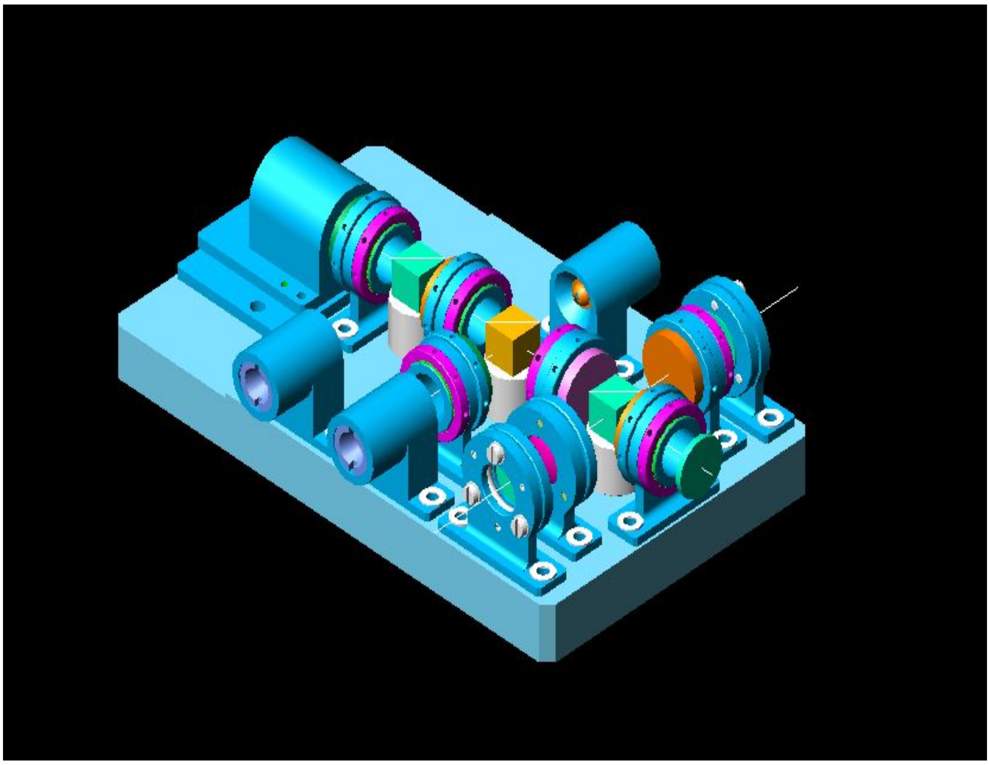

Figure 2. Prototype Development Interferometer Design

3 Further Measurements of Sensitivity

We have automated data acquisition from our prototype and have obtained data at target mirror displacements over a range of 1.75*mm* around equal optical paths with a resolution of 0.25*mm*. These experiments showed that the excess noise that was previously reported when the interferometer was operated off-null was environmentally generated. Further the general noise levels in the laser diode HL6314MG are similar to those of a He-Ne laser both attenuated to have the same input power to the interferometer. Shown in figure 3a and 3b, are spectra taken from the laser diode and the He-Ne, respectively. The average noise level for both lasers was less than $3.5\times10^{-12}\ mHz^{-1/2}$ at 75*Hz* . The noise floor is limited by the resolution of the ADC (12bits sampled at 50kHz) at approximately $6\times10^{-13} mHz^{-1/2}$. The shot noise limit is approximately $4\times10^{-14} mHz^{-1/2}$. In a final design the digitisation noise could be reduced by increasing the voltage gain so that the Lissajous figure spanned the input range of the ADC and also by increasing the resolution. At present the Lissajous figure has a diameter of about 3V compared with an input range of 10V. Using Advanced LIGO signal processing with 16bit resolution at 16kHz the shot noise limit should be easily achievable.

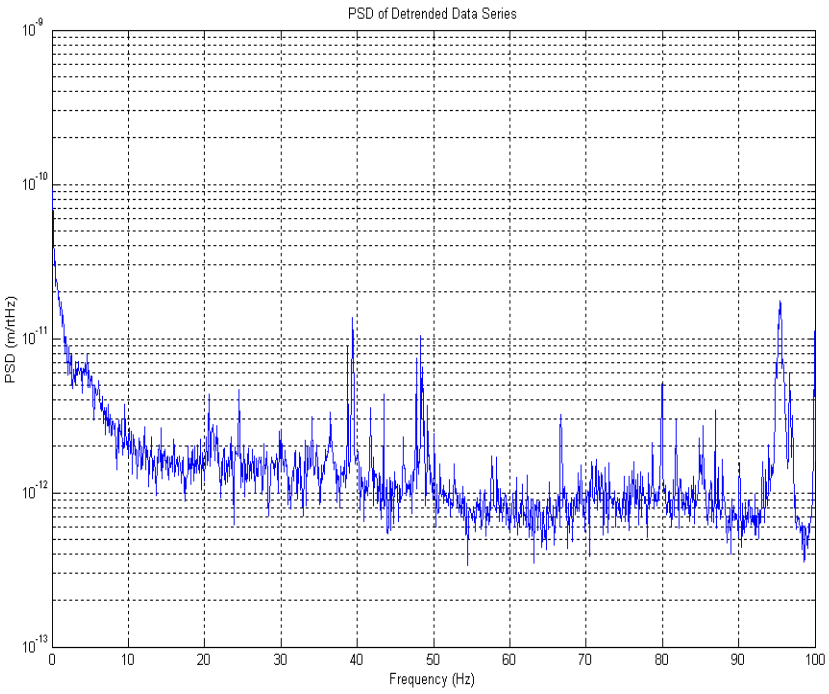

Figure 3a. Laser diode noise spectrum

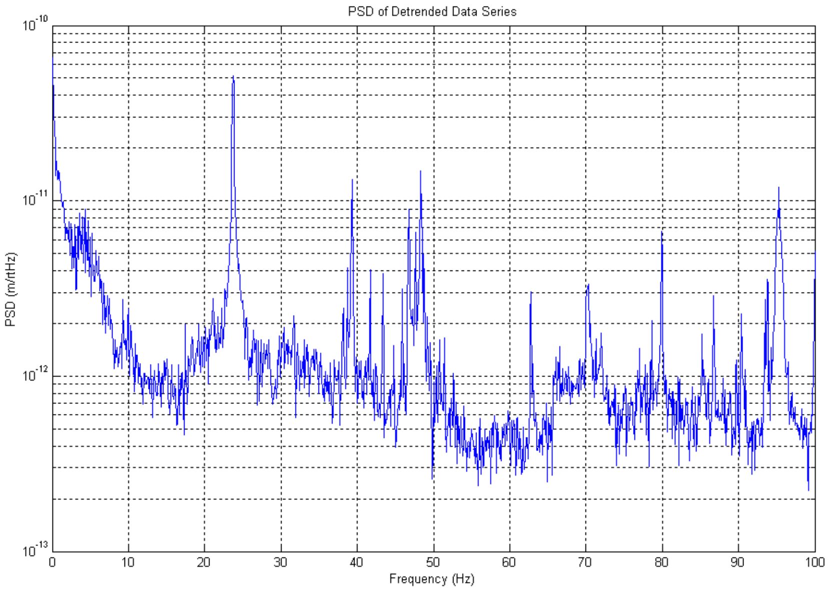

Figure 3b. He-Ne laser noise Spectrum

4 Laser Diode Spectral Characteristics

We have also investigated the output spectral characteristics of the Hitachi 6314MG laser diode to obtain its optimal drive current. We found that operation at the threshold current ensured single mode output of the laser diode. ‘Over’ driving the device, or running it at its ‘typical’ values, led to multiple output modes of the laser diode. These observations were made when the laser was temperature stabilised. Figure 4 shows a plot of the spectral characteristics of the device whilst operating at the threshold current level. The secondary mode can be seen at a wavelength $0.2nm$ longer than the dominant mode.

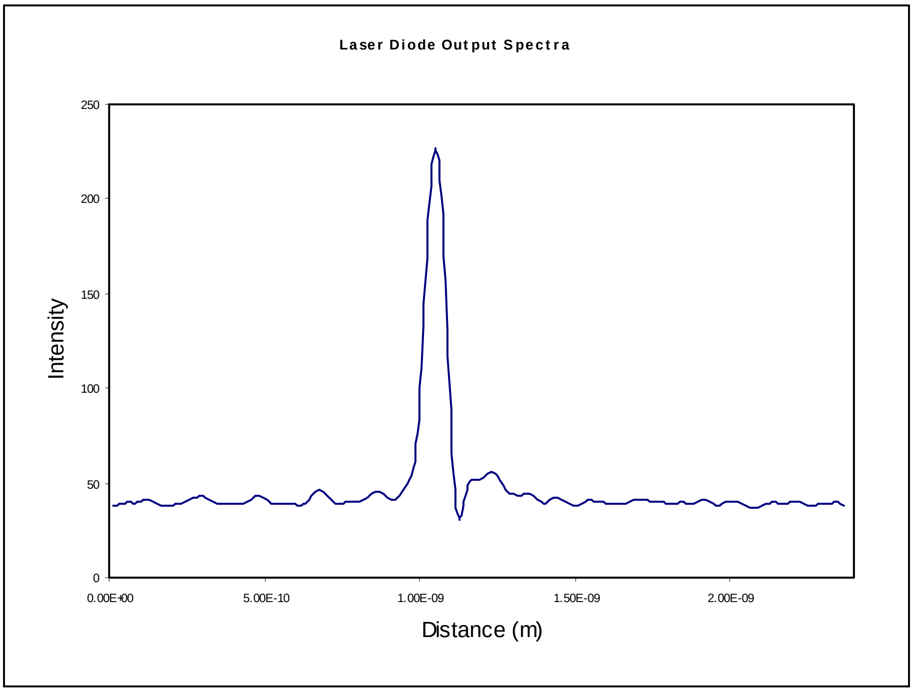

Figure 4. Plot of Laser Diode Spectra at threshold current ≈$25mA$ and $20C$

This mode separation gives rise to periodicities in the visibility of the fringes in the current design of interferometer of 0.5mm which were observed. The variation in visibility is negligible when the diode is operated in ‘mono-mode’ as in figure 4.

5 Tilt sensitivity

Examination of the optical paths traced out by the reference and measurement beams in the interferometer shows that, when the target mirror is tilted by θ, the target beam travels a distance, $2d$, equal to twice the distance between the target mirror and the cat’s eye lens, with an inclination of 2θ. This results in fringes given by the simple etalon equation $2d\cos 2\theta = n\lambda$. The interference fringe contrast collapses when the mirror misalignment results in a difference in $\lambda/2$ between the beams. In the laboratory set-up $d \approx 18cm$ which limits the tilt sensitivity to approximately $1.3mrad$. In the proposed prototype we would expect the tilt sensitivity to be improved.

6 References

[1] C. Speake, S. Aston. Interferometric OSEM Sensor Development. LIGO-T040044-01-K. March 2004.